ARMY RESEARCH LABORATORY

Leveraging Army Unique Mission Requirements to Advance the State-of-the-Art in Adhesives Development

by Robert Jensen, Wendy Kosik Chaney, Daniel DeSchepper, and David Flanagan

ARL-RP-360 **March 2012**

A reprint from the *Adhesion Society Newsletter*, Blacksburg, VA, December 2011.

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14. ABSTRACT
The selection and substitution of materials is the keystone of successful engineering. Ground vehicle armor represents a complex and broad spectrum of possible designs that are continually evolving to meet the protection needs imposed by ever-emerging threats. Adhesive selection plays a critical role in lightweight armor design. Hence, it is vital to capture, consolidate, and organize adhesive data in a meaningful way for both engineering design and material advancement. Many adhesives have been available from the commercial market over the years. Those intended for aerospace applications tend to have the highest pedigree engineering criteria defined within existing databases. The Army's adhesive needs push the quest for desirable properties well outside of the aerospace regime, which makes a trial and error selection approach both costly and time consuming. The vastness and variance in candidate adhesives and their potential applications for the Army create an overly complex material selection problem. The goal of this research is to capitalize on modern database and materials informatics capabilities to facilitate the advancement of adhesion science at a faster rate.

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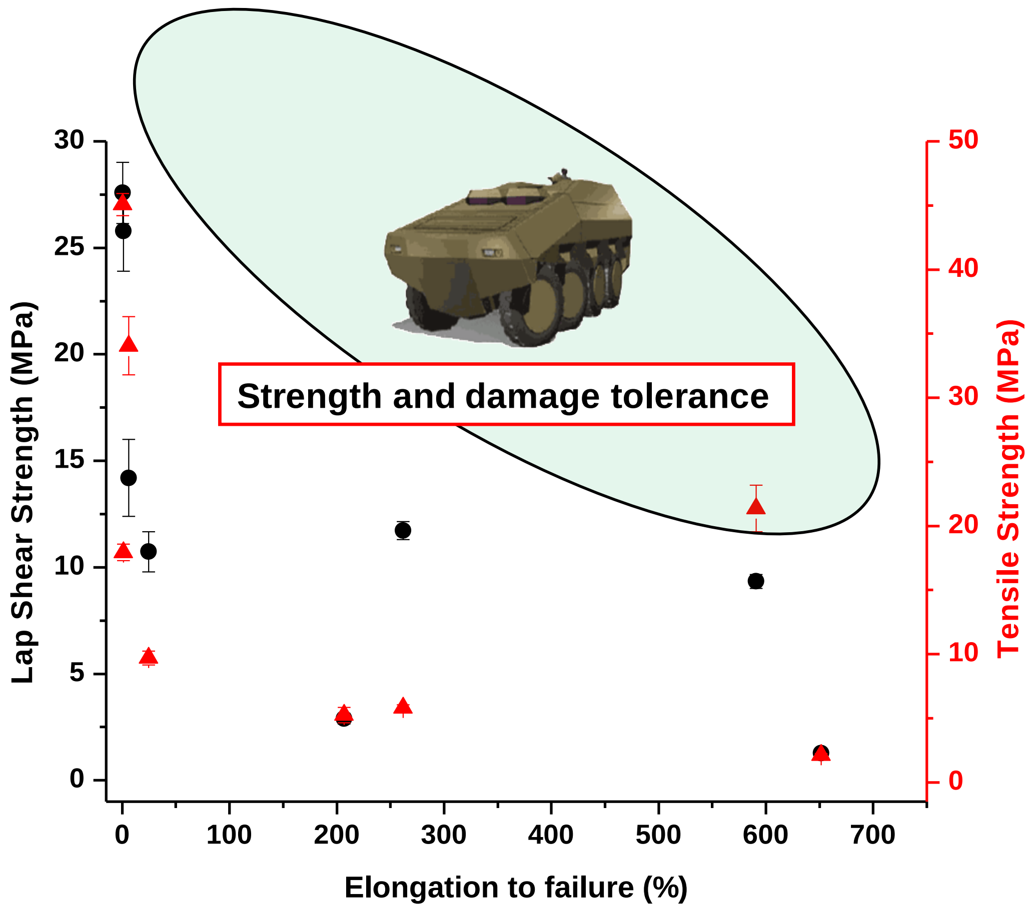
The selection and substitution of materials is the keystone of successful engineering. Ground vehicle armor represents a complex and broad spectrum of possible designs that are continually evolving to meet the protection needs imposed by ever emerging threats. Adhesive selection plays a critical role in light weight armor design. Hence, it is vital to capture, consolidate and organize adhesive data in a meaningful way for both engineering design as well as material advancement. A multitude of adhesives have been available from the commercial market over the years. Those intended for aerospace applications tend to have the highest pedigree engineering criteria defined within existing databases. The Army's adhesive needs push the quest for desirable properties well outside of the aerospace regime, which makes a trial and error selection approach both costly and time consuming.

The vastness and variance in candidate adhesives and their potential applications for the Army create an overly complex material selection problem. Candidate adhesives can include traditional high glass transition temperature (T_g) epoxy adhesives, but may also be expanded to include low T_g flexible epoxies, polyurethanes, methacrylates, epoxy-acrylate interpenetrating networks, polyurethane-epoxy hybrids, silicones, and hot-melt thermoplastics, as well as others. A large number of which have largely unknown mechanical and durability properties as rigorously required for engineering design criteria. To compound the difficulties, very little qualitative information exists for correlating basic quasi-static coupon level testing to empirically observed ballistic testing results. This leaves the basic adhesive property requirements for armor undefined.

Qualitative results obtained from high loading rate impact experiments performed during ARL testing indicate that high strength and low strain to failure adhesives show insufficient damage tolerance. Low strength and high strain to failure adhesives also demonstrate poor damage tolerance traits. Optimal adhesive performance, or rather a more promising potential direction under Army loading conditions, occurs where adhesives demonstrate both high strength and high strain to failure behavior. These results encourage the definition of a broad Army adhesive property regime. To that end, there is a need to gather standardized adhesive testing results at a level of fidelity suitable for rigorous engineering consideration.



Qualitative correlations between quasi-static and high loading rate testing indicates a very broad region of concurrent high strength/high elongation to failure that appears to be desirable for Army ground vehicle applications.

The Adhesive and Interfaces Research Team at ARL is currently investigating the potential for the relatively simple single-lap-joint, performed under typical quasi-static loading conditions, to screen adhesives with promising performance for Army applications. The correlations between single-lap-joint testing and high loading rate conditions will be derived internally at ARL, but it is essential to communicate the desired property requirements to outside commercial and academic formulators. Public disclosure of desired adhesive properties in the quasi-static domain is essential to advance the state-of-the-art to suit Army needs. Army derived adhesive properties requirements do not coincide with the traditional aerospace demands of high strength and high stiffness, which result from linear-elastic stress-strain behavior and very little energy absorption. High damage tolerance implies significant energy absorption and the often accompanying nonlinear stress-strain response. Therefore, the simplified approach of defining adhesive bond strength as peak load per unit surface area is inadequate to screen potential adhesives for ground vehicle use. Any potential Army defined adhesive property requirements must take the increased complexity of the nonlinear response into consideration, but without introducing an over burdensome calculation process into the standardization scheme. Preliminary results from ARL single-lap-joint testing suggest

that full descriptions of: the load versus displacement response; calculations of extension to failure; area under the curve; and the mode of failure are needed for a complete adhesive performance characterization. Ideally, the analysis scheme should be intentionally designed to perform under the constraints of a common spreadsheet program, thus eliminating the need for specialized software for reporting results to an Army derived single-lap-joint adhesive standard.

The commercial adhesive industry is extremely broad and diverse, with over 400 known commercial formulators world-wide. Preliminary feedback from outside commercial and academic ARL partners indicates a high level of interest in an Army driven adhesives specification. Through a DoD-NASA partnership, ARL has developed an adhesive database using the Materials Selection and Analysis Tool (MSAT) platform. Leveraging MSAT's real-time data management platform, we have refined our experimental data collection methodology to capture maximum detail, data pedigree, and integrity of non-aerospace adhesives on a large scale. As non-aerospace adhesives represent the dominant sector of the commercial market, streamlining the testing and data collection strategy is critical in achieving a reliable database flexible enough to respond to ever-shifting Army driven property requirements. It is a vision of the Adhesive and Interfaces Research Team to open portions of the MSAT adhesives database to the public domain. It is hoped that such public access will spur further development and innovation in adhesives research to other uses not directly connected to military applications. However, a key, and often underestimated, factor in the data collection is in the transference process from experimental testing results to digital format, which is focus of ongoing development in the Adhesive and Interfaces Research Team at ARL.

The potential adhesive property region relevant for Army ground vehicles could be significantly larger than the adhesive domain defined for aerospace. Materials informatics and data mining computational tools are now moving towards the practicality needed for drawing accurate correlations between complex high loading rate response and simpler quasi-static properties. More than just storing the data, the ability to retrieve relevant decision making information must be part of the value metric. Navigation tools are being explored to allow end users to search from "alternative point of views" using the same data. The goal is to enable a user friendly search platform for "non-adhesive experts" to find the critical parameters, response curve, or test set up all from the same verified source. We feel strongly that providing multiple scientific and engineering disciplines information from the same source will provide the impetus to move theoretical, model and experimental tests toward agreement/validation. The database will be extensively "hyperlinked" to allow end-users further detail of the data, test conditions or resulting reports.

Given the fundamental scientific obstacles with Army required adhesives, there could also be significant rewards for academic and industrial partners willing to invest research and development time into the issues. From the perspective of commercial interests, assuming that the Army's adhesive needs for ground vehicle armor applications can be successfully documented through unclassified published requirements with no association to actual armor performance, there is a rich historical precedent for militarily motivated technology to spur considerable growth in non-military commercial applications. With respect to academia, an Army derived specification for adhesives will also be unique when compared to aerospace. Armor needs will encompass a very broad range of

adhesive properties, many of which are likely unobtainable given current state-of-the art in materials design and processing capability. Innovation and advancement in technology requires a practical application for inspiration and motivation to pull higher risk ideas from the academic bench level into fruition in the real world. Here again, there are many historical and significant examples in which military applications provided a pivotal role in nurturing high-risk emerging technology. The Adhesive and Interfaces Research Team's development of the MSAT and informatics can be viewed as bringing traditional 20th century scientific rigor to a 21st century computational platform to facilitate the advancement of adhesion science at a faster rate.

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